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<p>(21) International Application Number: PCT/GB92/01173</p> <p>(22) International Filing Date: 29 June 1992 (29.06.92)</p> <p>(71) Applicant (for all designated States except US): LOUGHBOROUGH UNIVERSITY OF TECHNOLOGY [GB/GB]; Loughborough, Leicestershire LE11 3TF (GB).</p> <p>(72) Inventors; and (75) Inventors/Applicants (for US only) : VARDAXOGLU, John, Costas [GB/GB]; 63 William Street, Loughborough, Leicestershire LE11 3BX (GB). SEAGER, Robert, Dennis [GB/GB]; 6 Linden Road, Loughborough, Leicestershire LE11 1PG (GB). ROBINSON, Alan, John [GB/GB]; 30 New Street, Hepthorne Lane, North Wingfield, Chesterfield, Derbyshire S42 5JW (GB).</p>		<p>(74) Agents: RAYNOR, Simon, Mark et al.; Abel & Imray, Northumberland House, 303-306 High Holborn, London WC1V 7LH (GB).</p> <p>(81) Designated States: JP, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IT, LU, MC, NL, SE).</p> <p>Published <i>With international search report.</i></p>
<p>(54) Title: A WAVEGUIDE AND AN ANTENNA INCLUDING A FREQUENCY SELECTIVE SURFACE</p> <div data-bbox="375 1146 1300 1797"> </div> <p>(57) Abstract</p> <p>A waveguide (4) includes two frequency selective surfaces (5) mounted within the waveguide parallel to its side walls (6). The frequency selective surfaces (5) influence the frequency response of the waveguide (4).</p>		

A waveguide and an antenna including
a frequency selective surface.

The present invention relates to a waveguide including a frequency selective surface and an antenna including a frequency selective surface. More specifically, the invention relates to a tuneable multiband/broadband wave guiding system and aperture antenna.

Waveguides and antennas for electromagnetic radiation are generally designed to operate at one specific frequency or within a narrow frequency band. The aim of the present invention is to provide a waveguide and an antenna that have broad or multiple operating frequency bands. It is a further aim of the invention to provide a waveguide and an antenna that are tuneable to operate at different frequencies.

According to the present invention, there is provided a waveguide including a frequency selective surface, the frequency selective surface being arranged to influence the frequency response of the waveguide.

A frequency selective surface (FSS) is an array of antenna elements that acts as a passive electromagnetic filter. The surface may comprise an array of electrically conductive elements on a dielectric substrate or, alternatively, a plurality of apertures in a conductive surface. Electromagnetic waves incident on a surface comprising an array of conductive elements are reflected from the surface only in a narrow band of frequencies and

changed.

A reconfigurable frequency selective surface comprises at least two arrays of elements, the arrays being arranged in close proximity with one another so that elements of a first array are closely coupled with elements of a second array adjacent to the first array. The first array is displaceable with respect to the second array to adjust the frequency response of the surface.

10 The first and second arrays may be substantially parallel with one another.

The array elements may be conductive elements on a dielectric substrate, or apertures in a conductive substrate, or a combination of the above.

15 The first and second arrays may have a separation of no more than 0.03 wavelengths, and preferably no more than 0.003 wavelengths of the electromagnetic waves having the resonant frequency of the surface. For example, when microwaves of frequency 30GHz are to be reflected, the separation is advantageously no more than 0.225mm and preferably no more than 0.025mm.

25 The first array may be displaceable relative to the second array in a direction parallel to the surfaces of the arrays. Alternatively, the frequency selective surface may be reconfigured by rotating the first array with respect to the second array, or by altering the distance and/or the medium separating the first array from the second array. Using that configuration, there

8 and two side walls 6. Two frequency selective surfaces 5 are mounted parallel to its two side walls 6. The frequency selective surfaces 5 divide the waveguide longitudinally into two portions, an inner portion being defined by the upper and lower walls 7, 8 and the frequency selective surfaces 5, and an outer portion being defined by the upper and lower walls 7, 8 and the side walls 6.

The frequency selective surfaces 5 are arranged to transmit at low frequencies and to reflect at higher frequencies. The surfaces 5 are then invisible to the electromagnetic waves in the lower frequency band, and the effective internal dimensions of the waveguide 4 are defined by the side walls 6 and the upper and lower walls 7, 8 of the waveguide 4. At higher frequencies, the frequency selective surfaces 5 will reflect the electromagnetic waves, and the effective internal dimensions of the waveguide 4 will then be defined by the frequency selective surfaces 5 and the upper and lower walls 7, 8 of the waveguide. The effective dimensions of the waveguide are therefore different for different frequencies of transmitted electromagnetic wave, so increasing the operating frequency range of the waveguide.

The operating frequency range of the waveguide is defined at its lower end by the cut-off frequency in the outer waveguide of the dominant TE_{10} propagation mode, and at its upper end by the upper limit of the band-stop

tive surfaces, which may be fixed or reconfigurable and either single or multilayer structures, can be used to provide a number of waveguide devices, such as filters, polarisers or phase shifters. The surfaces may be
5 positioned at any location within a waveguide. The reconfigurable frequency selective surfaces may be electronically tuned, the speed of the tuning and the performance of each application being governed by the array design and the process of attaining the recon-
10 figurable frequency selective surface effect.

Figs. 8 and 9 show the results of experimental tests on the waveguides, which demonstrate the principles of operation of the waveguide. The results were obtained using the prototype waveguide shown in Fig. 7, which
15 consists of a standard X-band waveguide from which the narrow side walls have been removed. The waveguide comprises broad upper and lower conducting walls 9, 10 having on their inner faces several longitudinal slots 11 into which frequency selective surfaces can be inserted.

20 The transmission response of the prototype in the X band (8-12.4 GHz) is shown in Fig. 8. When operated without any inserts, the prototype exhibits a moderately lossy transmission band from the cut-off frequency up to about 16GHz. Placing radar-absorbing material (RAM)
25 along the lengths of the open sides of the waveguide increases insertion loss dramatically in the X-band, showing that fringing fields exist outside the waveguide when operated in this mode. When frequency selective

As shown in Fig. 9, similar results to those produced in the frequency selective surface/open wall case were produced when frequency selective surfaces were inserted into a standard X-band waveguide. The close proximity of the copper wall of the waveguide to the frequency selective surfaces does not significantly modify their guiding effect. The figure also shows the calculated reflection coefficient amplitude for a single layer large array of tripoles over the range 13 to 18 GHz. The array used in the waveguide was a single line of tripole elements. The reflection band of the large frequency selective surface is broadly similar to the enhanced transmission range measured in the test prototype. The frequency selective surface reflection coefficients were calculated using a Floquet mode analysis, assuming that the finite line array of tripoles behaves as an infinite rectangular lattice array with vertical periodicity equal to the waveguide height. The calculations also assumed a nominal incidence angle of 30° from normal (a reasonable approximation to the varying angles of incidence in the waveguide), to account for the oblique nature of the plane waves which may be used to describe the fields in the waveguide for the TE_{10} mode.

A broadband/multiband antenna, which operates according to the same principles as the waveguide described above, is shown in Figs. 10 and 11. Fig. 10 shows a broadband pyramidal horn antenna having an outer

with one another, so that the elements 3 of the first array 1 are closely coupled with the elements of the second array 2. The separation S of the arrays is as small as possible, whilst ensuring that the elements of
5 the first array 1 are electrically insulated from the elements of the second array 2, and will generally be of the order of 0.03 wavelengths or less, although this will depend on the particular array design, and the dielectric constant of the substrate.

10 The second array 2 is displaceable relative to the first array 1 by a small distance DS . In the embodiment shown in figure 1, the second array 2 can be displaced transversely, parallel to the surfaces of the arrays, in the direction of the Y -axis. Other types of displacement
15 are, however, possible: for example, the second array 2 could be displaced in the direction of the X -axis or the Z -axis (thereby altering the distance S separating the two arrays) or it could be rotated about the Z -axis, or displaced in any combination of those directions.

20 When the arrays 1,2 are aligned accurately with one another (so that $DS=0$), the elements 3 of the first array 1 lie directly over the elements of the second array 2, thereby shadowing the second array 2 from the incident electromagnetic waves. The frequency response of the
25 surface is then similar to that of a single array which, as shown in figure 4, includes a narrow reflection band and upper and lower transmission bands. The letters f_R denote the reflection band centre frequency, which

An example of the results that can be achieved with a particular reconfigurable frequency selective surface will now be described. The particular frequency selective surface consists of two arrays 1,2 of linear
5 dipoles 3, printed in a square lattice on a 0.037mm thick dielectric substrate of dielectric constant 3. The geometry of the lattice unit cell is shown in figure 3, wherein L represents the length of the antenna element, W the element's width, and D the side length of the unit
10 cell (equal to the separation of adjacent antenna elements). In the first array 1, $L=4.3\text{mm}$, $W=0.4\text{mm}$ and $D=6\text{mm}$. In the second array 2, $L=3.25\text{mm}$, $W=0.4\text{mm}$ and $D=6\text{mm}$. Each array is square, having sides of length 20cm, and the separation S between the arrays is about
15 0.225mm.

The measured and theoretical response of the surface to microwaves of frequency 12-40GHz at both normal incidence and a TE incidence of 45° , with the electric field parallel to the dipoles, is shown in figure 5. By
20 comparison, the variation in the frequency response of a single array with increasing dipole length is shown as a solid line at the top of the graph.

When the two arrays are substantially aligned, with DS in the range 0 to 0.625mm, the frequency response of
25 the surface is similar to that of a single array having the dimensions and lattice arrangement of the first array 1. Resonance takes place at frequencies of about 31GHz and 27GHz for normal and TE: 45° states of incidence

loops or any other type of antenna element. The elements need not necessarily be arranged periodically and the arrays may be planar or curved. The frequency selective surface may further consist of two or more closely-
5 coupled arrays of elements, and the respective arrays may either be displaced in a direction parallel to the surfaces of the arrays, or rotated or their separation altered, or the medium separating the arrays may be adjusted (for example, by adjusting its dielectric
10 constant).

The relative displacement of the two arrays may be controlled in various different ways. For example, piezoelectric actuators can be used to control the precise relative movement of the arrays, and the arrays
15 can be printed directly onto the piezoelectric material. The frequency selective surface may have piezoelectric actuators positioned at some sub-areas of its surface, i.e. not everywhere on its surface. Alternatively, the arrays can be mounted at a small separation and air
20 pumped from the gap between the arrays to alter their separation.

displaceable with respect to the second array to adjust the frequency response of the surface.

7. An antenna for microwave radiation, comprising a outer horn and an inner horn, wherein the inner horn
5 includes a frequency selective surface.
8. An antenna according to claim 7, in which the outer horn includes a frequency selective surface.
9. An antenna according to claim 7 or claim 8, in which the inner and outer horns are coaxial.
- 10 10. An antenna according to any one of claims 7 to 9, in which the horns have a rectangular transverse cross-section.
11. An antenna according to any one of claims 7 to 9, in which the horns have a circular transverse cross-
15 section.
12. An antenna according to any one of claims 7 to 11, in which at least one frequency selective surface is a reconfigurable frequency selective surface.
13. A waveguide according to claim 1, in which a
20 frequency selective surface is provided over an open end of the waveguide.

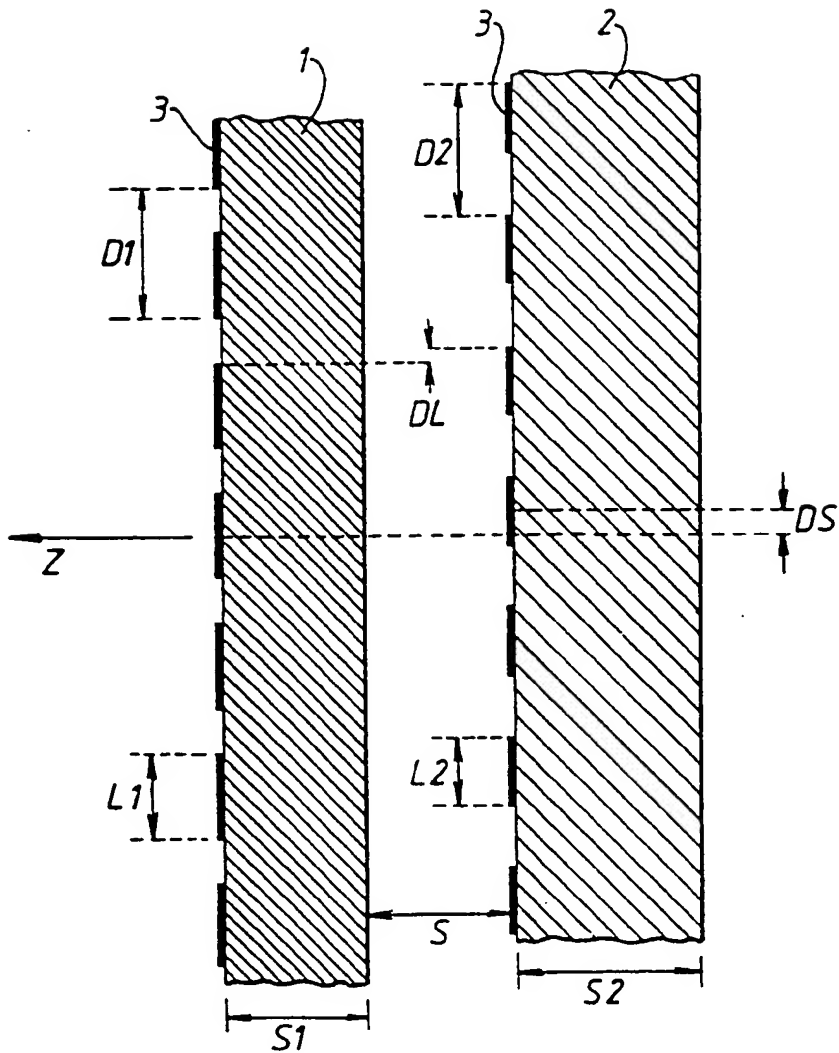


Fig.2.

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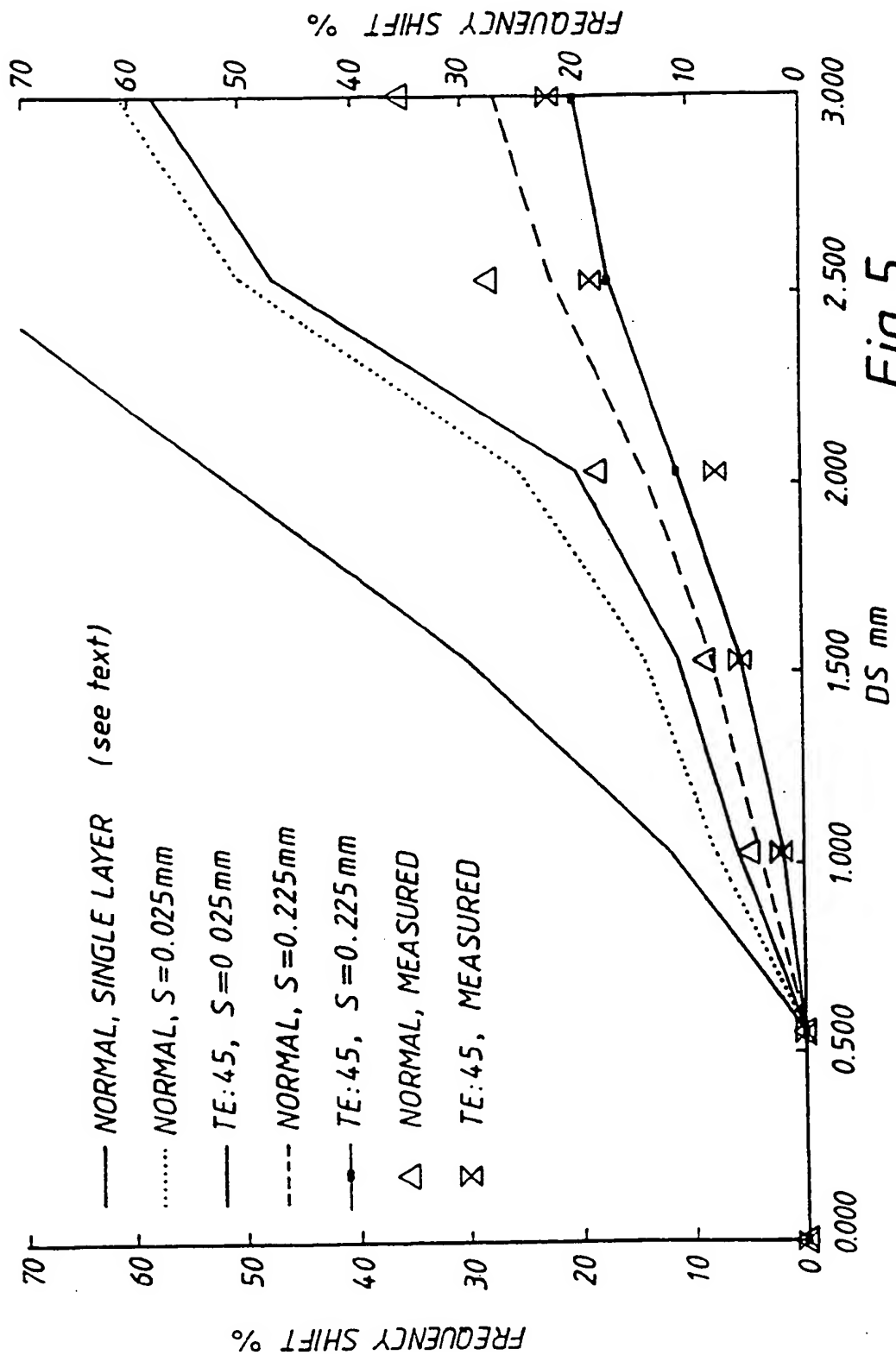


Fig. 5.

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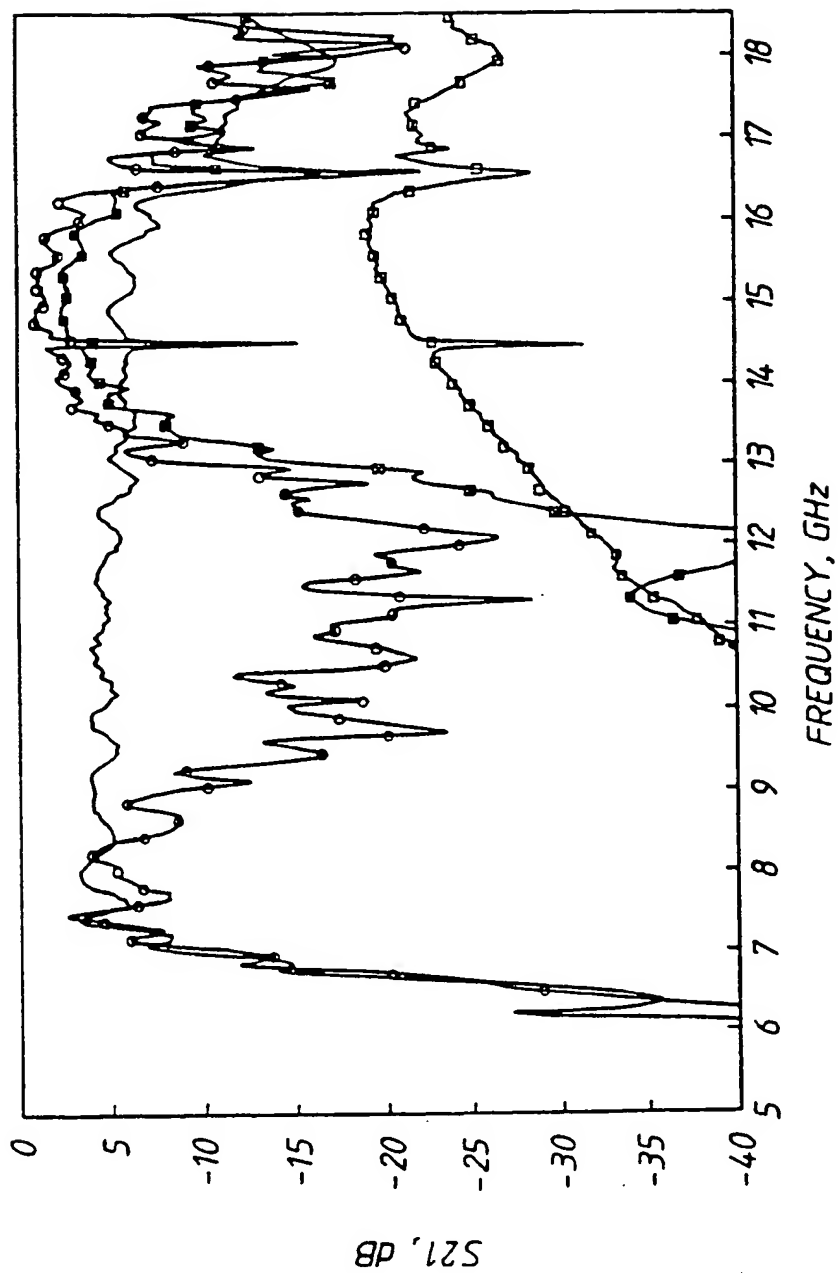
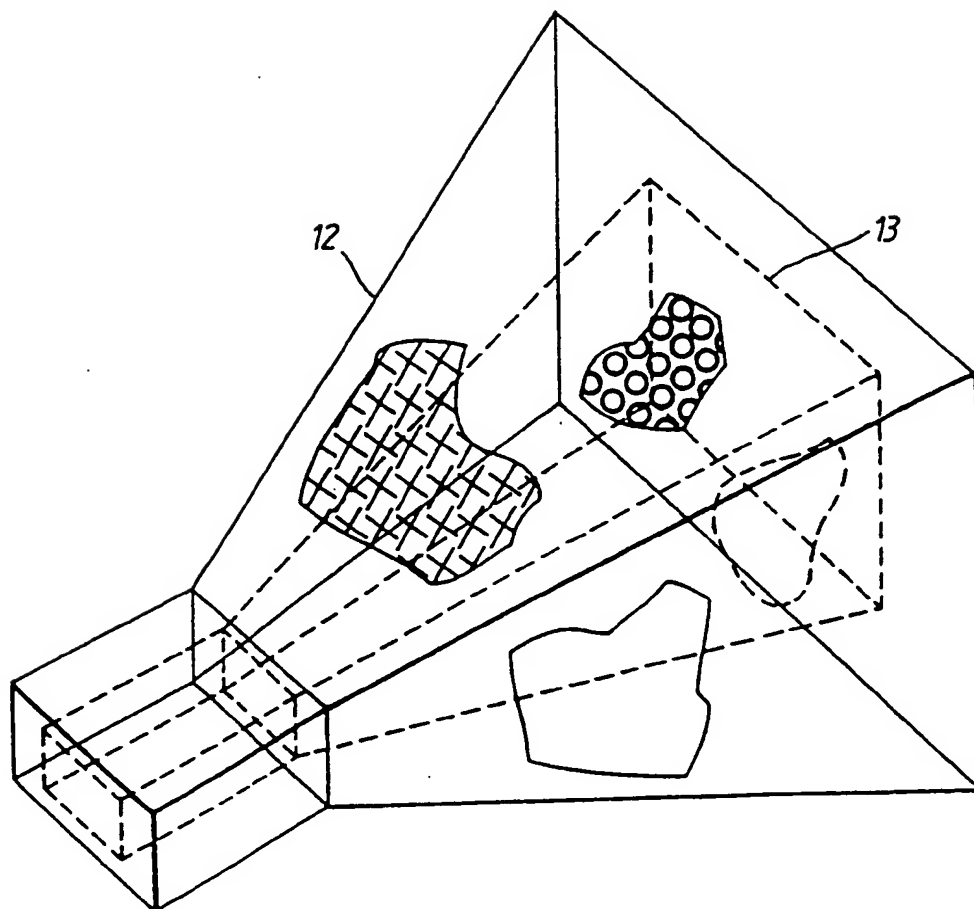


Fig.8.

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*Fig.10.*

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INTERNATIONAL SEARCH REPORT

PCT/GB 92/01173

International Application No

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)⁶

According to International Patent Classification (IPC) or to both National Classification and IPC
 Int.Cl. 5 H01Q15/00; H01Q13/02; H01P3/12

II. FIELDS SEARCHED

Minimum Documentation Searched⁷

Classification System

Classification Symbols

Int.Cl. 5

H01Q ;

H01P

Documentation Searched other than Minimum Documentation
 to the Extent that such Documents are Included in the Fields Searched⁸

III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹

Category ¹⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	US,A,3 633 206 (MCMILLAN) 4 January 1972 see column 3, line 1 - line 46 see column 10, line 8 - line 54; figures 1,3A,B ---	1, 13
X	PATENT ABSTRACTS OF JAPAN vol. 014, no. 584 (E-1018)27 December 1990 & JP,A,22 54 801 (MIYATA YOSHIHIDE) see abstract ---	7
A	US,A,4 028 650 (KONISHI ET AL.) 7 June 1977 see claims 1-5; figures 1-17 ---	1-6
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¹⁰ Special categories of cited documents:

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search

26 FEBRUARY 1993

Date of Mailing of this International Search Report

05.03.93

International Searching Authority

EUROPEAN PATENT OFFICE

Signature of Authorized Officer

ANGRAEIT F.F.K.

**ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.**

GB 9201173
SA 61615

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on
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26/02/93

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US-A-3028565		None	
EP-A-0468623	29-01-92	None	
GB-A-2253519	09-09-92	None	

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82